BABAR Results on Leptonic & Radiative B Decays

G. Eigen, Bergen

Representing the BABAR collaboration

SUSY2011, 30-08-2010

Topics in this Talk

- Measurements of direct *CP* asymmetry in inclusive $B\to X_{(s+d)}\gamma$ decays

- Evidence for $B^{\pm}\to\tau^{\pm}\nu$

- Measurement of $D^{\pm}_{s}\to\ell^{\pm}\nu$ branching fractions and decay constant f_{Ds}
  ➔ impact on the m_{H+} -tanβ plane in MSSM

- Search for $D^{+}_{(s)}/\Lambda^{+}_{c}\to h^{\pm}\ell^{-}\ell^{+}$ decays

Leptonic and Radiative Decays

- Leptonic & radiative decays have small branching fractions in the SM (10^{-4}-10^{-9}), since they involve some suppression mechanisms, e.g.:
  - ➔ higher order processes become leading (penguin loops, box diagrams in radiative decays & rare semileptonic decays)
  - ➔ CKM suppression ($b \to u$ processes)
  - ➔ helicity suppression (W-annihilation)

- Suppressed processes are very sensitive to new physics contributions which may be similar in size and may interfere with the SM processes producing sizable deviations from the SM prediction
  - ➔ such processes are very suitable for new physics searches providing a complementary approach to direct searches at the Tevatron & LHC

- With the large data samples of the B-factories (BABAR:426 fb^{-1} & Belle: 711 fb^{-1} at $\Upsilon(4S)$) it became possible to explore rare decays in the $b\bar{b}$ and $c\bar{c}$ systems with branching fractions down to 10^{-7}

- Measurements of $B \to X_s\gamma$ and related processes have set stringent constraints on the SUSY parameter space already probing New Physics at scale of a few TeV

Isidori, Nir, Perez
arXiv:1002.0900 (2010)

Measurement of Direct CP Asymmetry in Inclusive $B \to X_{(s+d)}\gamma$ Decays

Motivation for $B \to X_{s+d}\gamma$ Studies

- The decays $B \to X_s\gamma$ & $B \to X_d\gamma$ proceed at leading order via loop diagrams
- In the SM, the $B \to X_s\gamma$ branching fraction at NNLO for $E_\gamma > 1.6$ GeV is

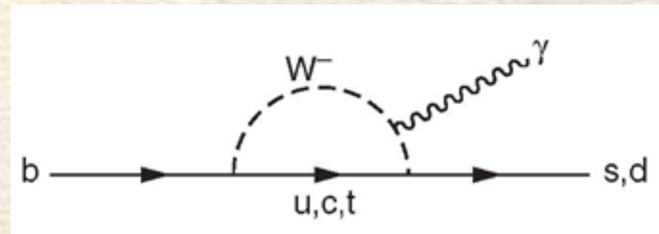
$$\mathcal{B}_{SM}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

Misiak et *al*., PRL 98, 022002 (2007)

- World average is consistent with the SM

$$B(B \to X_s\gamma) = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$$

HFAG 2011



- New physics contributions may increase the branching fraction
- Direct *CP* asymmetry is another observable sensitive for NP effects

$$\mathcal{A}_{CP}(B \to X_{s+d}\gamma) = \frac{\mathcal{B}(\bar{B} \to X_s\gamma + \bar{B} \to X_d\gamma) - \mathcal{B}(B \to X_s\gamma + B \to X_d\gamma)}{\mathcal{B}(\bar{B} \to X_s\gamma + \bar{B} \to X_d\gamma) + \mathcal{B}(B \to X_s\gamma + B \to X_d\gamma)}$$

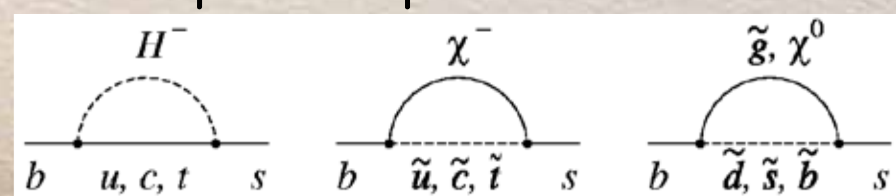
Hurth et *al*.,
Nucl.Phys. B704, 56 (2005)

- SM predicts $\mathcal{A}_{CP}(B \to X_s\gamma) \sim 0.0044$ $\mathcal{A}_{CP}(B \to X_d\gamma) \sim -0.102$

$$\mathcal{A}_{CP}(B \to X_{s+d}\gamma) \sim \mathcal{O}(10^{-6})$$

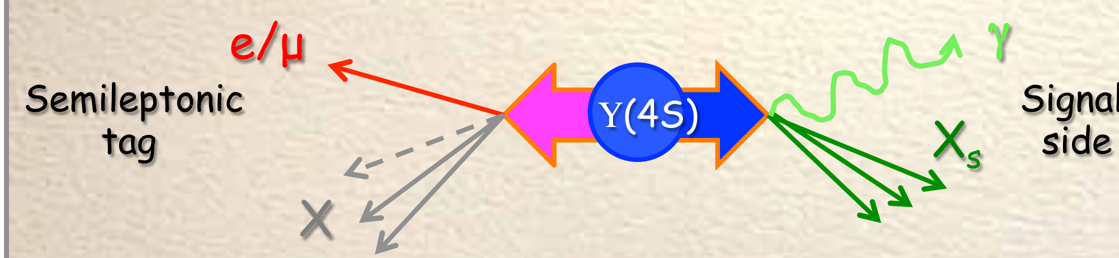
Benzke et *al*.,
PRL106, 141801 (2010)

- Other interesting observables involve the photon spectrum moments
  - Allow for extraction of heavy quark parameters m_b, μ^2_π,… (in progress)



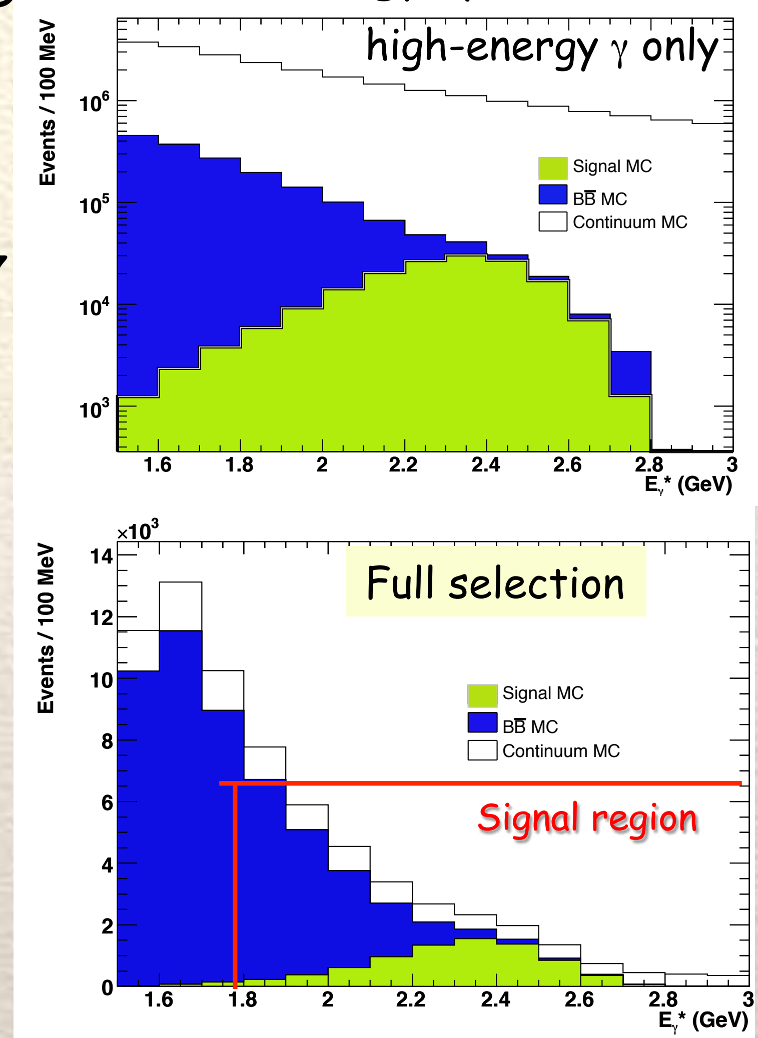
$B \to X_{s+d}\,\gamma$ Analysis Strategy (fully inclusive)

- Use 347 fb^{-1} of $\Upsilon(4S)$ data ➔ 3.8×10^8 $B\bar{B}$
- Use e & μ tags to reduce $q\bar{q}$ backgrounds
  - ➔ $p^*_{e(\mu)} > 1.05$ GeV/c
  - ➔ missing energy $E_{miss} > 0.7$ GeV
  - ➔ angle between e(μ) & γ: $\cos\theta^*_{e(\mu)\gamma} > -0.7$



- Suppress continuum background
  - using neural network based on event shape variables
  - subtract off-resonance data
- Suppress $B\bar{B}$ background mainly from $\pi^0\to\gamma\gamma$ and $\eta\to\gamma\gamma$ by explicit vetos

Photon energy spectra



- Estimate remaining backgrounds using data and perform cross checks with control samples

Results on $B \to X_{s+d}\gamma$ *CP* Asymmetry

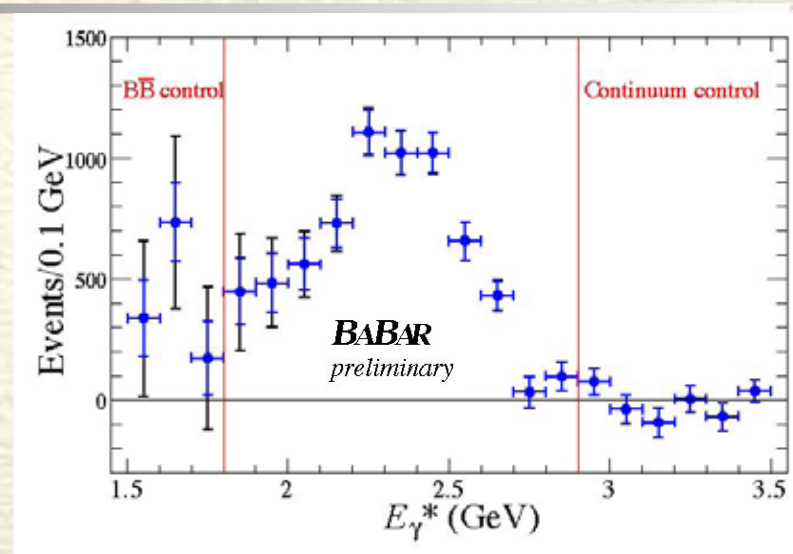
- Checks of control regions agree with with null hypothesis

  $B\bar{B}$ control (at 1.4σ): $1.53 < E^*_\gamma < 1.8$ GeV

  $N_{\Upsilon(4S)} - N_{bg(MC)} = 1252 \pm 272 \pm 841$ events

  $q\bar{q}$ continuum control: $2.9 < E^*_\gamma < 3.5$ GeV

  $N_{\Upsilon(4S)} - N_{off} = -100 \pm 138$ events



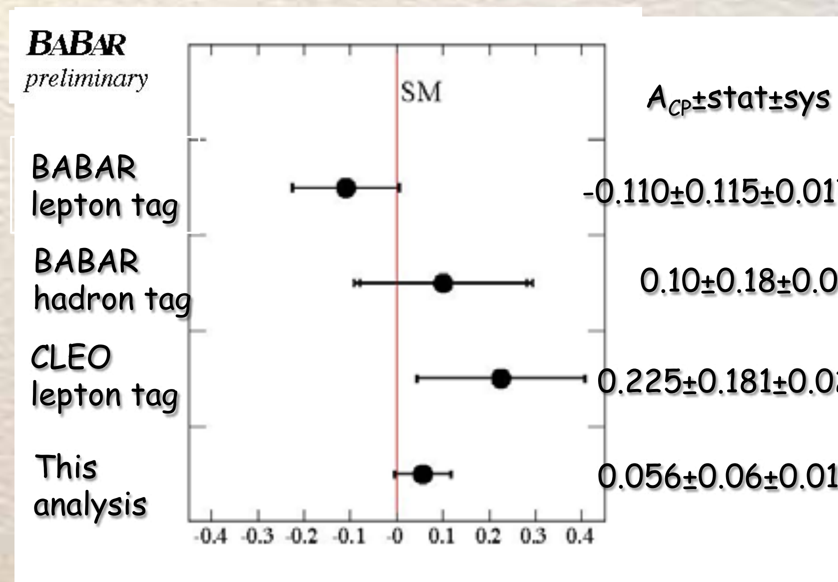
- $\mathcal{A}_{CP}$ is independent of E^*_γ selection
  ➔ optimized for 2.1-2.8 GeV region

- Lepton charge determines B flavor
  ➔ 2623 ± 158 ℓ^+ events
  ➔ 2397 ± 151 ℓ^- events

- Correct for mistag rate $\omega = 0.131 \pm 0.007$ & bias $\Delta\mathcal{A}_{CP} = 0.004 \pm 0.006$

$$\mathcal{A}_{CP} = \frac{1}{1-2\omega}\mathcal{A}_{CP}^{meas} + \Delta\mathcal{A}_{CP}$$

- Measure $\mathcal{A}_{CP} = 0.056 \pm 0.060 \pm 0.018$

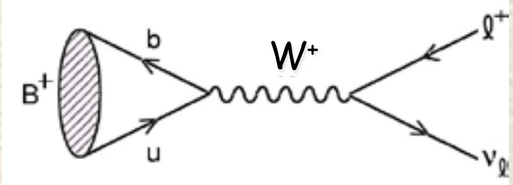


which agrees with the SM prediction (due to large experimental uncertainties)

Evidence for $B^{\pm} \longrightarrow \tau^{\pm}\nu$

$B^{\pm}$ Leptonic Decays

- $B^{\pm}\to\tau^{\pm}\nu_{\tau}$ is a weak annihilation process (helicity suppressed)



- The SM branching fraction is proportional to the decay constant f^2_B & $|V_{ub}|^2$

$$\mathcal{B}_{SM}(B\to\tau\nu)=\frac{G_F^2}{8\pi}m_B m_\tau^2\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2\left|V_{ub}\right|^2\tau_B$$

- f_B is determined in unquenched lattice calculations

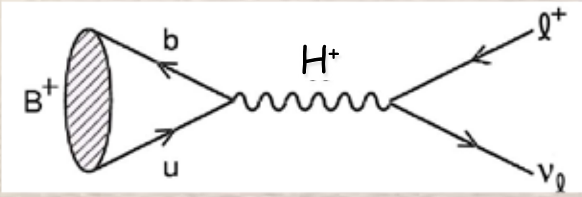
$$f_B = 191\pm3\pm13\ \text{MeV}$$

Lenz et *al.*, PRD 83, 036004 (2011)

- For $V_{ub}=(3.89\pm0.44)\times10^{-3}$ (PDG 10) calculate

$$\mathcal{B}_{SM}(B^{\pm}\to\tau^{\pm}\nu)=(0.98\pm0.23_{V_{ub}}\pm0.13_{f_B})\times10^{-4}$$

- Extra contribution may come from a charged Higgs boson, modifying the branching fraction



Hou, PRD 48, 2342 (1993)

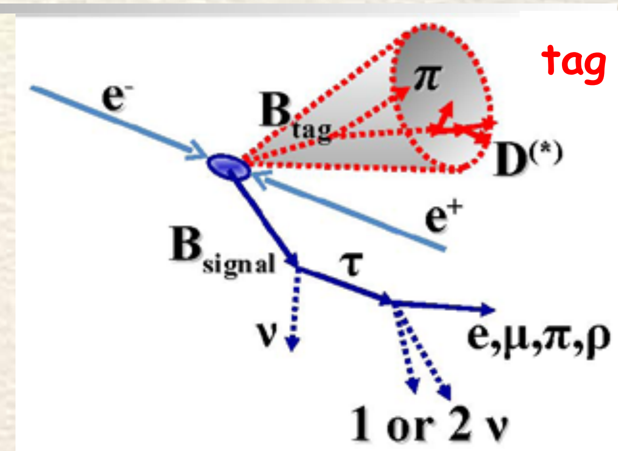
$$\mathcal{B}(B^{\pm}\to\tau^{\pm}\nu)=B_{SM}(B^{\pm}\to\tau^{\pm}\nu)\times r_H$$

$$r_H=\left(1-\frac{m_B^2}{m_{H^+}^2}\frac{\tan^2\beta}{1+\varepsilon_0\tan\beta}\right)^2$$

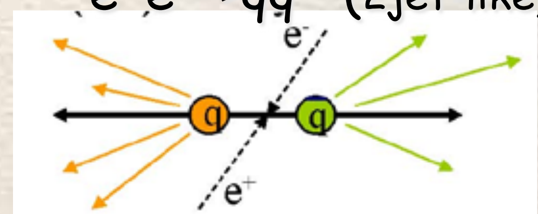
ε_0~0.01 (radiative correction)

$B^{\pm} \rightarrow \tau^{\pm}\nu$ Analysis Strategy

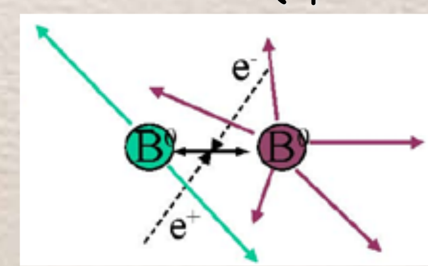
- Reconstruct ("tag") one B meson in hadronic $B^{\mp} \rightarrow D^{(*)0}X^{\mp}$ or $B^{\mp} \rightarrow J/\psi X^{\mp}$ decays ε^{h}_{tag} ~1%
- Look for signal $\tau^{\pm} \rightarrow e^{\pm}\bar{\nu}\nu,\ \mu^{\pm}\bar{\nu}\nu,\ \pi^{\pm}\nu,\ \rho^{\pm}\nu$ in the recoil
- Sample: 426 fb^{-1} (467 million $B\bar{B}$ events)
- Use kinematic constraints and event shape information to select signal
- Study extra neutral energy in event, E_{extra}, i.e. the energy of all photons in the EMC that do not belong to the signal nor the reconstructed tag
  ➔ for correctly reconstructed tags this is the summed noise in the EMC
- Total selection efficiency $\varepsilon=(8.1\pm0.1)\times10^{-4}$



$e^{+}e^{-} \rightarrow q\bar{q}$ (2jet-like)



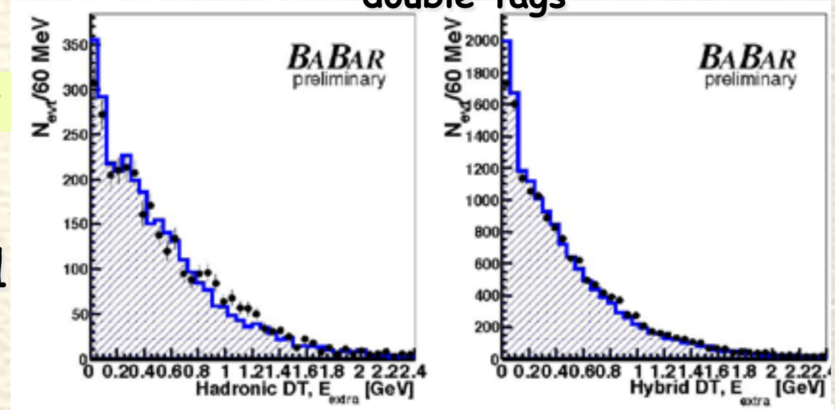
$e^{+}e^{-} \rightarrow B\bar{B}$ (spherical)



$B^{\pm}\to\tau^{\pm}\nu$ Results

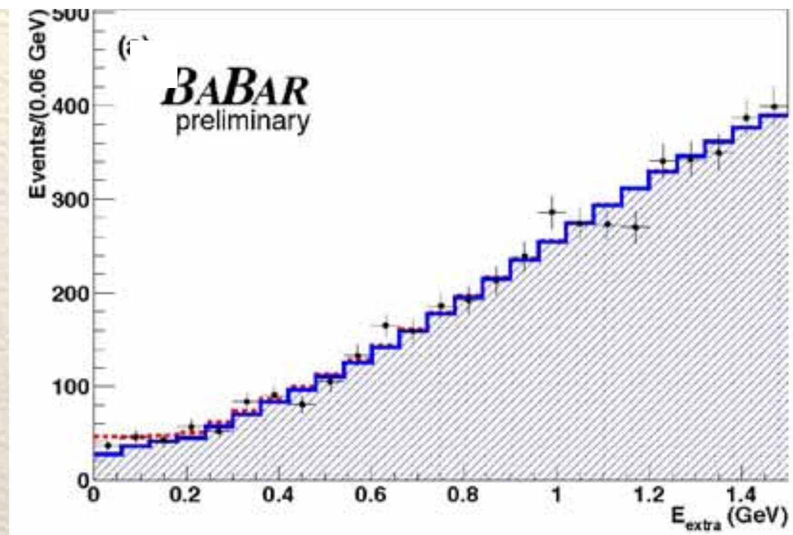
- Check data/MC agreement with double tags: $B^{-}\to D^{(*)0}X^{-}\ vs\ B^{+}\to \bar{D}^{(*)0}X^{+}$ & $B^{-}\to D^{(*)0}X^{-}\ vs\ B^{+}\to (\bar{D}^{(*)0}X^{+}+\bar{D}^{(*)0}\ell^{+}\nu)$

double tags



- Apply data/MC correction: 0.926±0.01

- Extract $\mathcal{B}(B^{\pm}\to\tau^{\pm}\nu)$ from unbinned maximum likelihood fit to E_{extra} distribution in the 4 modes combined



- Observe a signal with 3.3σ significance including systematic uncertainties

- BABAR measures (hadronic tags):

$$\mathcal{B}(B^{\pm}\to\tau^{\pm}\nu)=(1.8^{+0.57}_{-0.54}\pm 0.26)\times 10^{-4}$$

Del Amo Sanchez et *al*., hep-ex/1008.0104

- Combine result with previous analysis that used semileptonic tags ➔ $\mathcal{B}(B^{\pm}\to\tau^{\pm}\nu)=(1.76\pm 0.49)\times 10^{-4}$

Aubert et *al*, PRD 77, 011107 (2008)

- This is consistent with the Belle measurement ➔ $\mathcal{B}(B^{\pm}\to\tau^{\pm}\nu)=(1.54^{+0.38+0.29}_{-0.37-0.31})\times 10^{-4}$

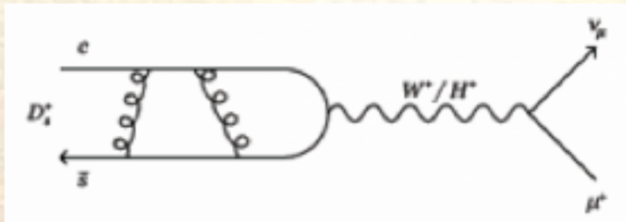
Hara et *al*., PRD 82, 071101 (2010)

Measurements of $D^{\pm}_{s} \rightarrow \tau^{\pm}\nu$ Branching Fractions and f_{Ds}

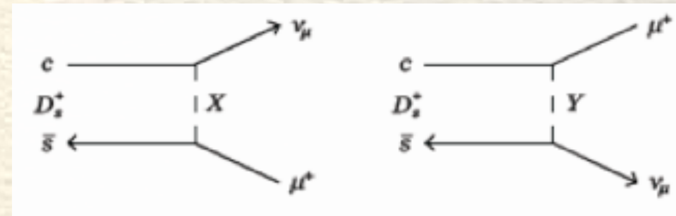
$D^{\pm}_s$ Leptonic Decays

- $D^{\pm}_s \to \ell^{\pm}\nu$ proceeds via W-annihilation similar as $B^{\pm} \to \tau^{\pm}\nu$

W boson/
Charged Higgs



Leptoquarks



- New physics contribution involve a charged Higss and leptoquarks

- $D^{\pm}_s \to \ell^{\pm}\nu$ is well suited to measure the decay constant f_{Ds}, since theoretical uncertainties are small

- In the SM, the $D^{\pm}_s \to \ell^{\pm}\nu$ branching fraction is given by

$$\mathcal{B}_{SM}(D_s \to \ell\nu) = \frac{G_F^2}{8\pi} m_{D_s} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_{D_s}^2}\right)^2 f_{D_s}^2 \left|V_{cs}\right|^2 \tau_{D_s}$$

- New Physics may enhance branching fraction

Dobrescu & Kronfeld.,
PRL 100, 241802 (2008)

- In MSSM, the branching fraction is enhanced by the factor r_H

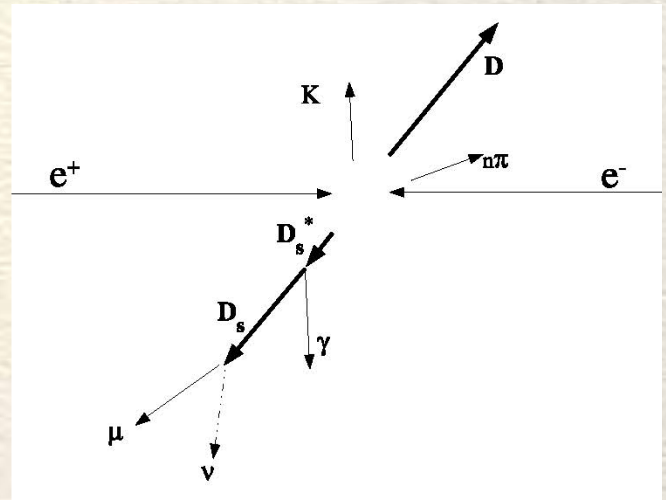
$D_s^\pm \to \ell^\pm \nu$ Analysis Strategy

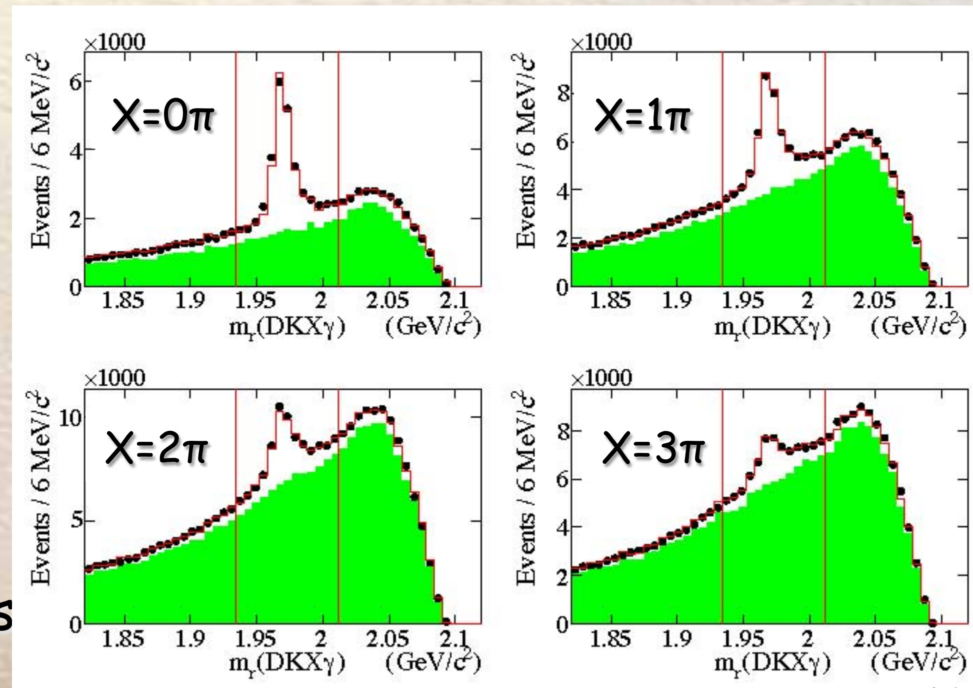
- Attempt to fully reconstruct events
  $e^+e^- \to c\bar{c} \to DKXD^{*+}_s$, with $D^{*+}_s \to D^\pm_s \gamma$, $D^\pm_s \to \ell^\pm \nu$
- ℓ= e, μ, or τ; K= K^+ or K^0_S; X= # of π's (≤3)
- Reconstruct D tag hadron fully in D^0, $D^\pm$ and $\Lambda^\pm_c$ decays
- Use 677×10^6 $c\bar{c}$ events ($\mathcal{L}$=521 fb^{-1})
- Obtain normalization samples by reconstructing the recoil mass

$$m_r^2 = \left[p_{e^+} + p_{e^-} - \left(p_D + p_K + p_X + p_\gamma\right)\right]^2$$

- Extract $D^\pm_s$ yield from 2-d fit to recoil mass and # of reconstructed π's

➔yield $(67.2\pm1.5)\times10^3$ $D^\pm_s$ events

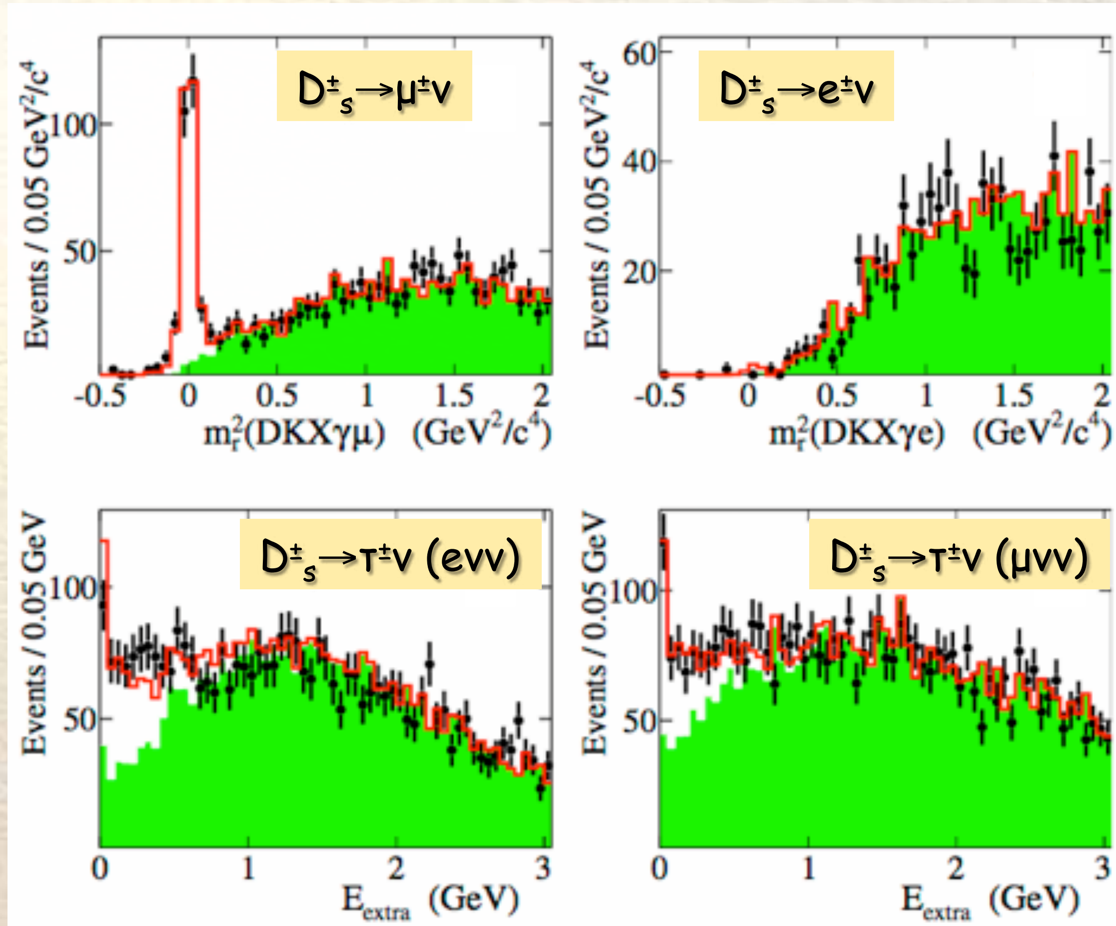




PRD RC 82, 091103 (2010)

$D^{\pm}_s \to \ell^{\pm}\nu$ Results

- Select D_s signal region & reconstruct 4 final states
  - $D_s^{\pm} \to \mu^{\pm}\nu,\ e^{\pm}\nu$
  - $D_s^{\pm} \to \tau^{\pm}(\to \mu^{\pm}\nu\bar{\nu},\ e^{\pm}\nu\bar{\nu})\nu$
- For $D^{\pm}_s \to \mu^{\pm}\nu,\ e^{\pm}\nu$ extract signal yield from binned fit to recoil mass m_r
- For $D^{\pm}_s \to \tau^{\pm}\nu$ modes, study extra neutral energy in the event, E_{extra} (same as used in $B^{\pm} \to \tau^{\pm}\nu$)
- Except for the $e^{\pm}\nu$ mode, see significant signal yields



Aubert et *al.*, PRD RC 82, 091103 (2010)

Aubert et *al.*, PRD RC 82, 091103 (2010)

f_{Ds} Results

- Determine $\mathcal{B}(D^{\pm}_s \to l^{\pm}\nu)$ & f_{Ds} for each mode

Mode	$\mathcal{B}[10^{-3}]$	f_{Ds} [MeV]
$D^{\pm}_s \to e^{\pm}\nu$	<0.23@90%CL	-
$D^{\pm}_s \to \mu^{\pm}\nu$	6.02±0.38±0.34	265.7±8.4±7.7
$D^{\pm}_s \to \tau^{\pm}\nu$ $(\tau \to e\nu\bar{\nu})$	50.7±5.2±6.8	247±13±17
$D^{\pm}_s \to \tau^{\pm}\nu$ $(\tau \to \mu\nu\bar{\nu})$	49.1±4.7±5.4	243±12±14

- Average $\mathcal{B}$ of 2 τ decay channels

$$\mathcal{B}(D^{\pm}_s \to \tau^{\pm}\nu) = (49.8 \pm 5.5) \times 10^{-3}$$

- Average 3 f_{Ds} measurements

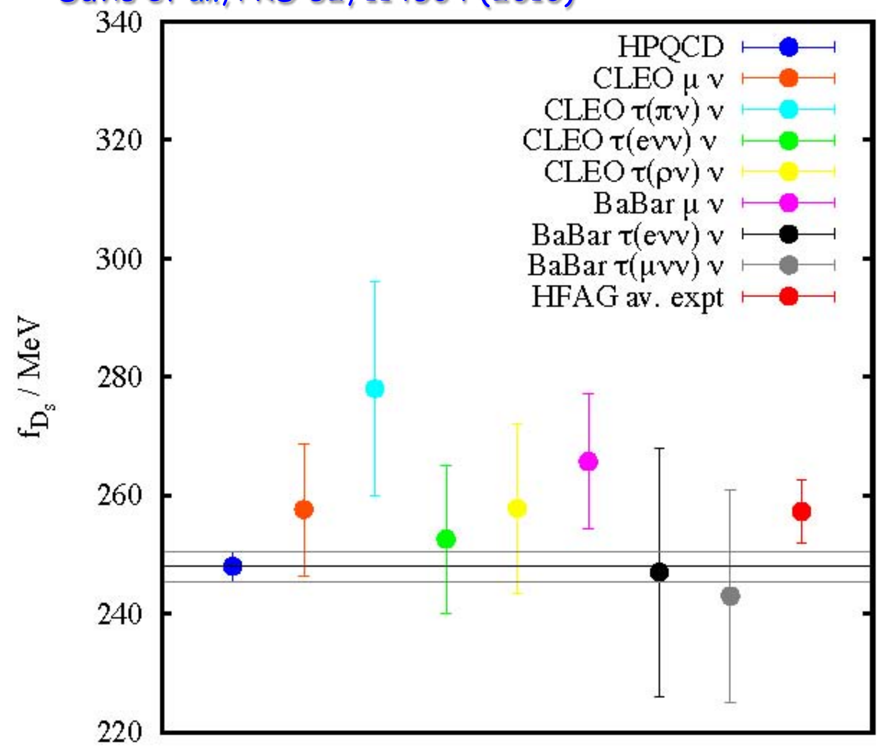
$$f_{D_s} = (258.6 \pm 6.4 \pm 7.5)\ \text{MeV}$$

- Result is consistent at the 1.6σ level with the LQCD prediction of

$$f_{D_s} = (248.6 \pm 2.5)\ \text{MeV}$$

- BABAR results are in good agreement with measurements from CLEO

Davis et *al.*, PRD 82, 114504 (2010)

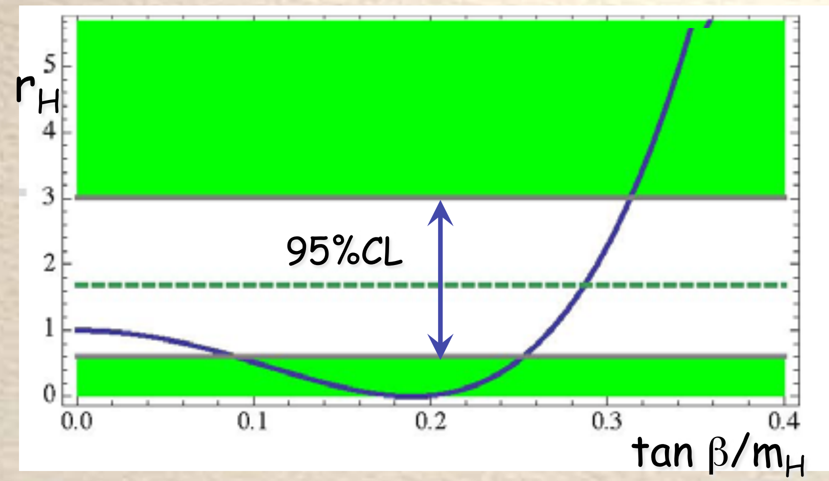


Constraints in the m_H-tanβ Plane (MSSM)

- From HFAG average

$$\mathcal{B}(B^{\pm} \to \tau^{\pm}\nu) = (1.64 \pm 0.34) \times 10^{-4}$$

yield $r_H = 1.69 \pm 0.36_{exp} \pm 0.45_{f_B, V_{ub}}$

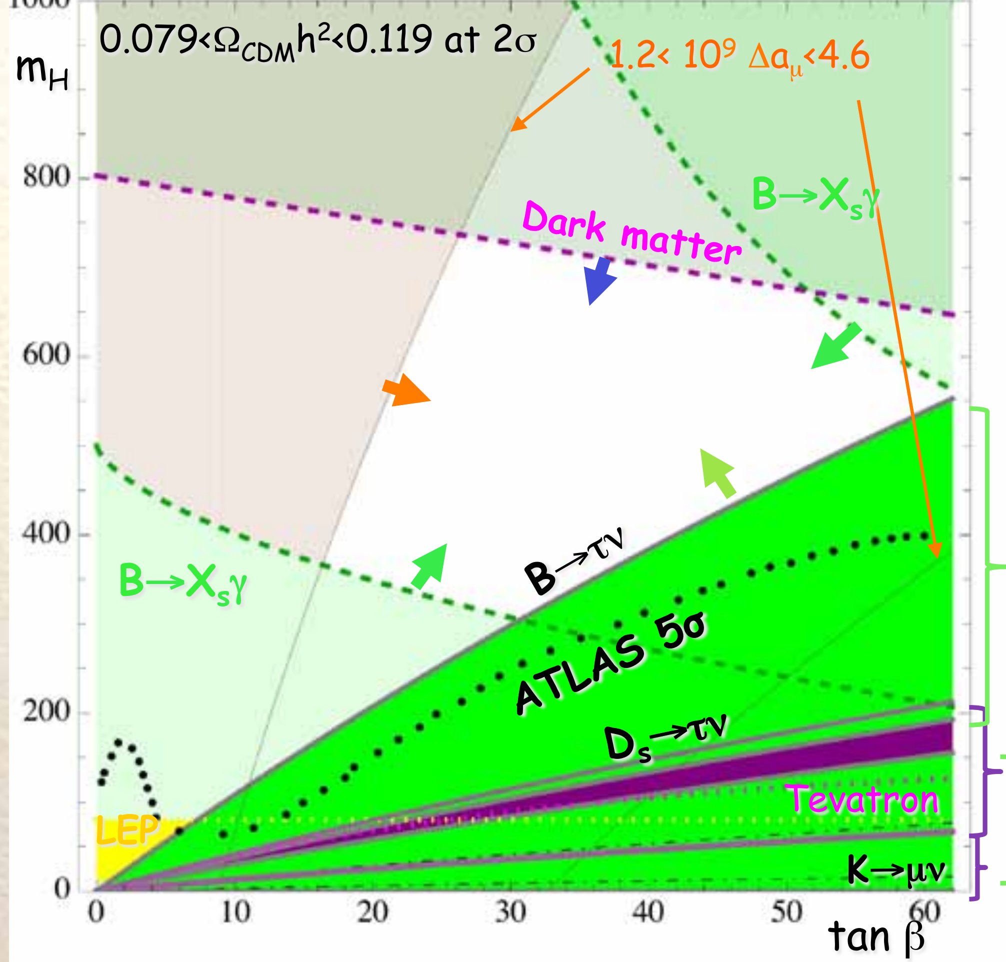


- BABAR $D^{\pm}_s \to \tau^{\pm}\nu$ results yield

$r_H = 0.88 \pm 0.11_{exp} \pm 0.02_{f_{D_s}}$

- Use also measurements for $\mathcal{B}(B \to X_s\gamma)$, CDM density, & a^{exp}_{μ}-a_{μ}^{SM} wrt MSSM

95% C.L. exclusions



Isidori et *al.*: PRD 75, 115019 (2007)

- Set $m_{\tilde{q}} = 1.5$ TeV, $A_u = -1$ TeV, μ=0.5 TeV, $m_{\tilde{\ell}} = 0.4$ TeV

- ATLAS: 5σ discovery for 30fb^{-1}

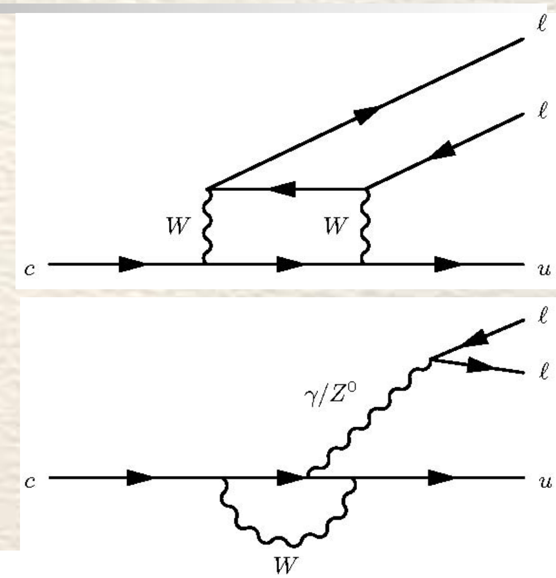
Search for

$D^{+}_{(s)}/\Lambda^{+}_{c} \rightarrow h^{+}\ell^{+}\ell^{-}$

Motivation for $D^{\pm}_{(s)}/\Lambda^{\pm}_{c} \to h^{\pm}\ell^{+}\ell^{-}$ Searches

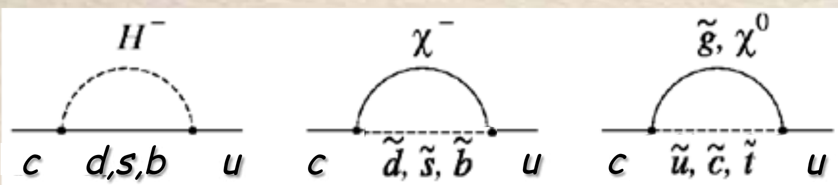
- $X^{\pm}_{c} \to h^{\pm}\ell^{-}\ell^{+}$ are flavor-changing neutral currents mediated by EW penguin processes that are highly suppressed in the SM

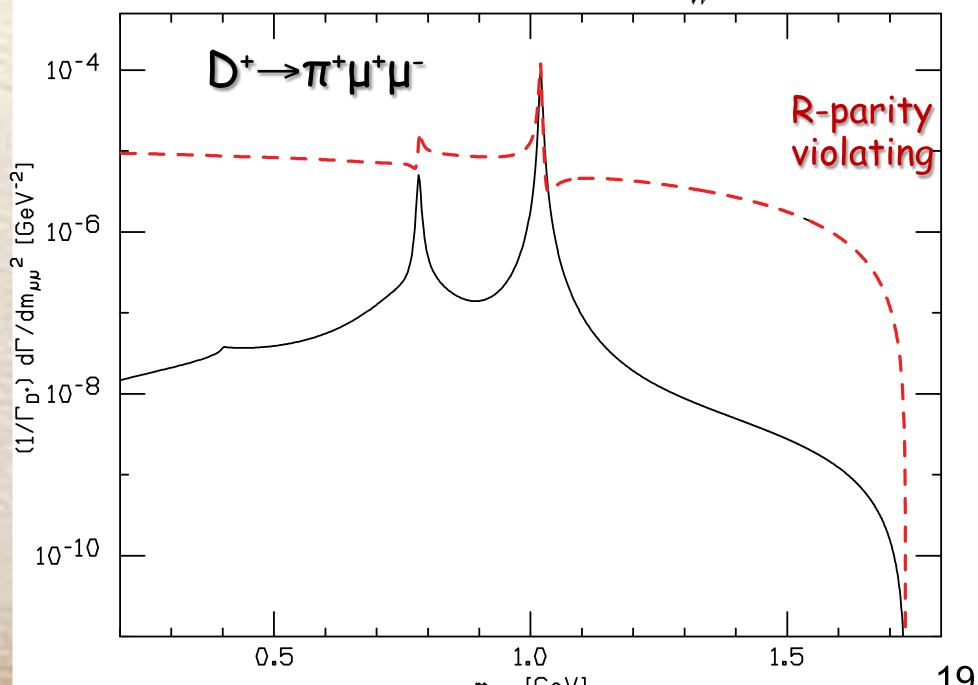
$$\mathcal{B}\left(D \to X_{u}\ell^{+}\ell^{-}\right) \sim \mathcal{O}(10^{-8})$$



- This is 2 orders of magnitude smaller than the SM prediction for $\mathcal{B}(B \to X_{s}\ell^{+}\ell^{-})$

- New Physics contributions may increase $\mathcal{B}(D \to X_{u}\ell^{+}\ell^{-})$

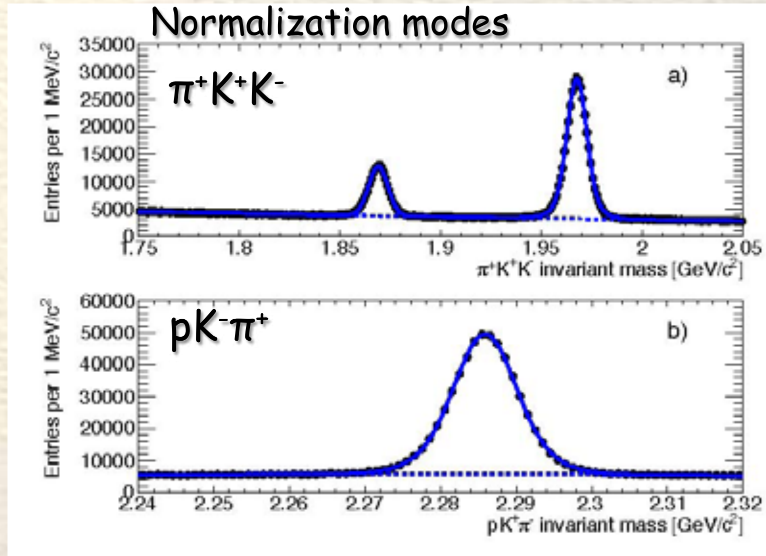




  - e.g. R-parity violating SUSY models can enhance $\mathcal{B}(D \to X_{u}\ell^{-}\ell^{+})$ up to $\mathcal{O}(10^{-5})$

Analysis Strategy for $D^+_{(s)}/\Lambda^+_c \to h^\pm \ell^- \ell^+$

- Using $\mathcal{L}$=384 fb^{-1} near $\Upsilon(4S)$, BABAR searched for $X_c \to h^\pm \ell^- \ell^+$ modes with $X_c = D^\pm, D^\pm_s, \Lambda^\pm_c$; $h^\pm = \pi^\pm, K^\pm, \overset{(-)}{p}$; $\ell\ell = e^+e^-, \mu^+\mu^-$ (10 modes)



- Select π, K or p and 2 well-identified leptons (e, μ) with $p^*_{K\ell\ell} > 2.5$ GeV/c (rejects $b \to c$)

- Reject QED events (> 5 hadrons)

- Reject semileptonic B & charm decays with common $\ell^-\ell^+$ vertex and likelihood ratio that is based on $p^*_{K\ell\ell}$, total reconstructed energy and the flight length significance

- Extract signal yields from an unbinned maximum likelihood fit to $h^\pm \ell^+ \ell^-$ invariant mass

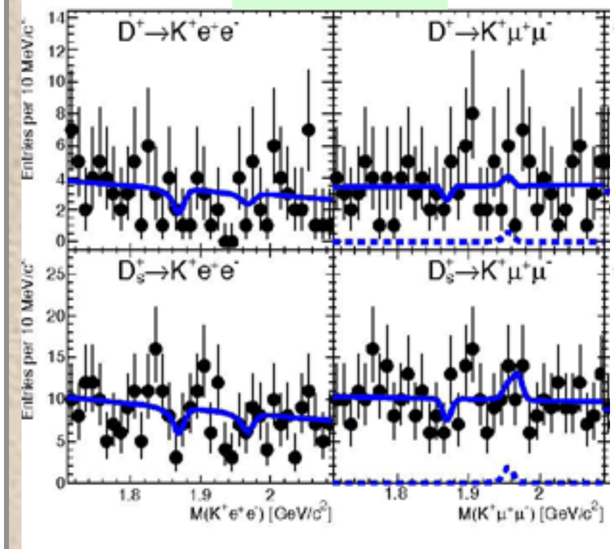
- Use $D^+_s \to \Phi(\to K^+K^-)\pi^+$ and $\Lambda^+_c \to pK^-\pi^+$ modes for normalization

- Signal efficiencies range from 0.4% to 6.8%

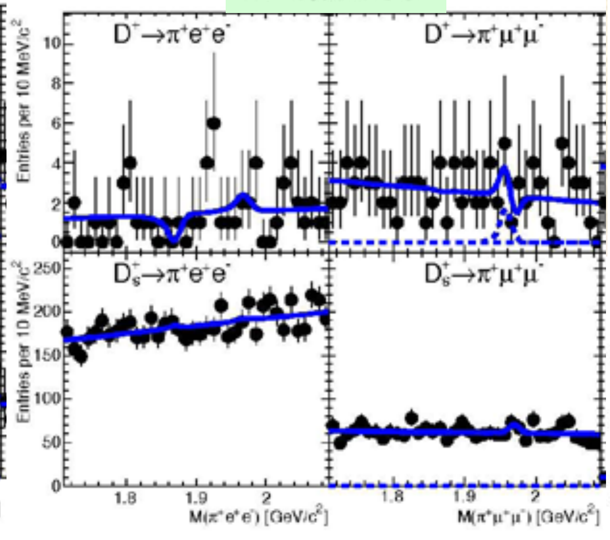
Results for $D^{\pm}_{(s)}/\Lambda^{\pm}_{c} \to h^{\pm}\ell^{+}\ell^{-}$

- Invariant $h\ell^{+}\ell^{-}$ mass distributions show no evidence for signal

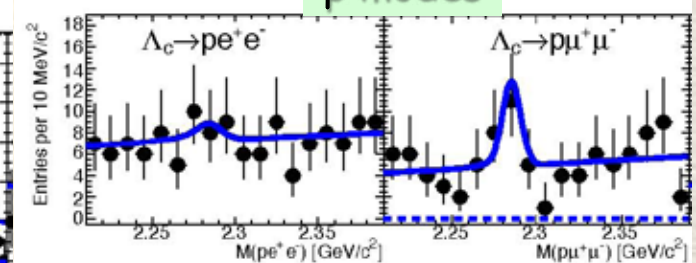
K± modes



π± modes



p modes

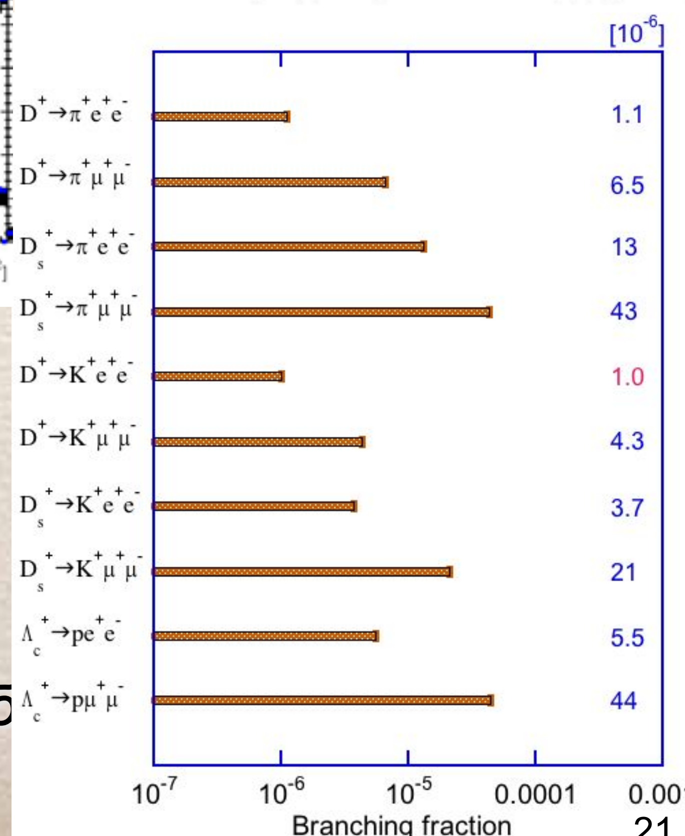


- Set $\mathcal{B}$ upper limits @90% CL, improve 7 previous limits & set first limit on $\Lambda^{\pm} \to p\mu^{+}\mu^{-}$

- Lowest limits is found for $D^{\pm} \to K^{\pm}e^{+}e^{-}$

$$\mathcal{B}(D^{\pm} \to K^{\pm}e^{+}e^{-}) < 1.0 \times 10^{-6} @90\%\ CL$$

- Fernando Martinez will present results on 25 lepton-flavor violating modes in session 8E



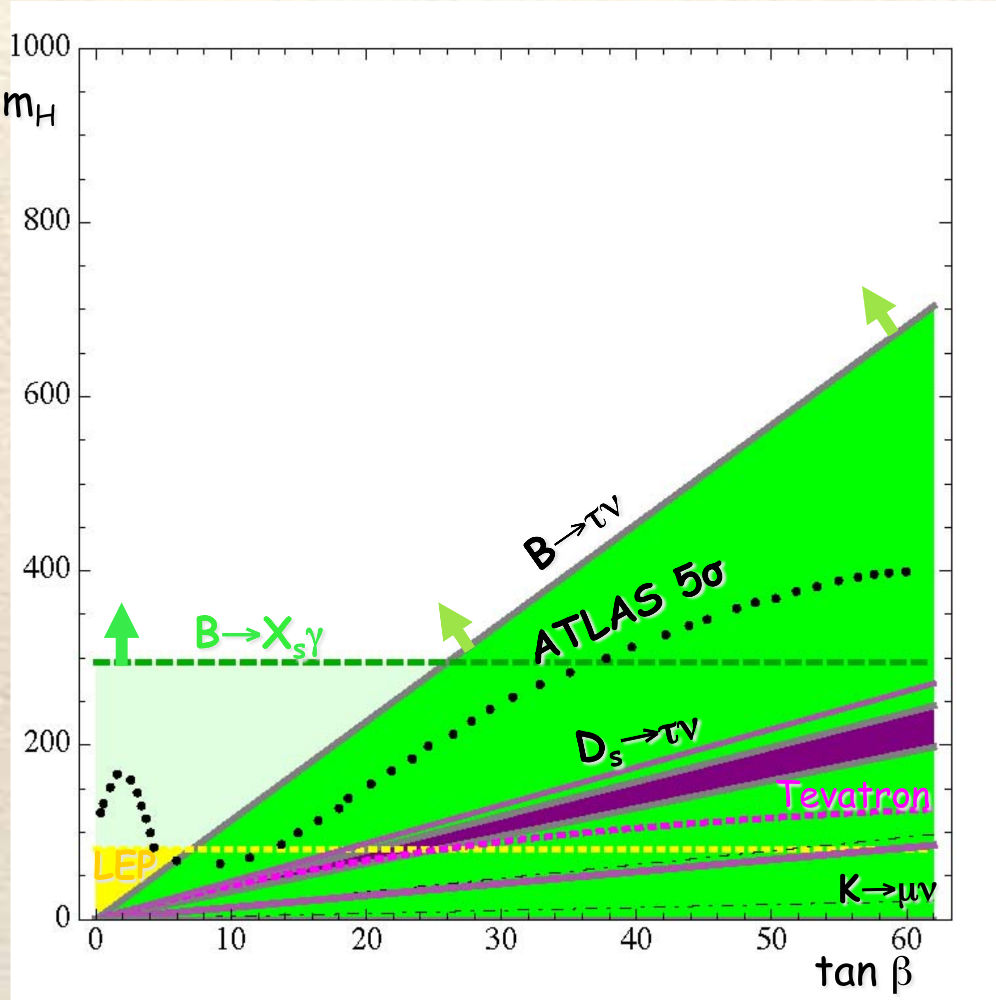
Conclusion

- The $B \to X_{s+d}\gamma$ *CP* Asymmetry is consistent with the SM prediction
  - ➔ present uncertainties are quite large
- BABAR sees evidence for $B^{\pm} \to \tau^{\pm}\nu$ at 3.3σ significance level (incl. sys)
  - ➔ measured branching fraction is in good agreement with the Belle result and is nearly 2σ above the SM prediction
- BABAR measures f_{Ds} in $D^{\pm}_{s} \to \tau^{\pm}\nu$ & $D^{\pm}_{s} \to \mu^{\pm}\nu$
  - ➔ Averaged with CLEO measurements f_{Ds} lies 1.6σ above SM prediction
- $\mathcal{B}(B^{\pm} \to \tau^{\pm}\nu)$, $\mathcal{B}(D^{\pm}_{s} \to \tau^{\pm}\nu)$, & $\mathcal{B}(B \to X_{s+d}\gamma)$ set stringent constraints in the m_H-$\tan\beta$ plane
- $X^{\pm}_{c} \to h^{\pm}\ell^{-}\ell^{+}$ decays are not seen by BABAR, (improve 8 previous limits)
  - ➔ best limit (10^{-6}) is found for $D^{\pm} \to K^{\pm}e^{+}e^{-}$,
- Significant improvements of these measurements will come from the Super B-factories (stay tuned)

Backup Slides

Constraints in the m_H-tanβ Plane (2HDM)

95% C.L. exclusions



- ATLAS: 5σ discovery for $30 fb^{-1}$

Aubert et *al.*, PRD RC 82, 091103 (2010)

f_{Ds} Results

- Determine $\mathcal{B}(D^\pm_s \to l^\pm \nu)$ & f_{Ds} for each mode

Mode	Yield	$\mathcal{B}[10^{-3}]$	f_{Ds} [MeV]
$D^\pm_s \to e^\pm \nu$	6.1±2.2±5.2	<0.23@90%CL	-
$D^\pm_s \to \mu^\pm \nu$	275±17	6.02±0.38±0.34	265.7±8.4±7.7
$D^\pm_s \to \tau^\pm \nu\ (\tau \to e\nu\bar{\nu})$	408±42	50.7±5.2±6.8	247±13±17
$D^\pm_s \to \tau^\pm \nu\ (\tau \to \mu\nu\bar{\nu})$	340±32	49.1±4.7±5.4	243±12±14

- Average 2 τ decay channels

$$\mathcal{B}(D^\pm_s \to \tau^\pm \nu) = (49.8 \pm 5.5) \times 10^{-3}$$

- Average 3 f_{Ds} measurements

$$f_{D_s} = (258.6 \pm 6.4 \pm 7.5)\ \text{MeV}$$

- This is consistent at the 1.6σ level with the LQCD prediction of

$$f_{D_s} = (248.6 \pm 2.5)\ \text{MeV}$$

- BABAR results are in good agreement with measurements from CLEO

Davis et *al.*, PRD 82, 114504 (2010)